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ANALYSIS METHODS FOR THEMATIC MAPPER DATA OF URBAN REGIONS

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I. ABSTRACT

Studies have indicated the difficulty in deriving a detailed land-use/land-cover classification for heterogeneous metropolitan areas with Landsat MSS and TM data. The major methodological issues of digital analysis which possibly have effected the results of classification are examined. In response to these methodological issues, a multichannel hierarchical clustering algorithm has been developed and tested for a more complete analysis of the data for urban areas.

II. INTRODUCTION

Remote sensing from satellites has been a technological breakthrough in monitoring the spatial-temporal nature of the earth efficiently and economically. It has taken only one decade to apply the satellite data to numerous fields ranging from weather prediction, water resources assessment, cultural resources management, urban land use analysis, crop forecasting, timber and wildlife monitoring, and mineral exploration to rangeland and wetland mapping (Colwell, 1983; Lillesand and Kiefer, 1979, pp. 528-597). The applications of the data within each field, however, vary in extent. For example, urban land use analysis using Landsat data has focused on boundary delineation between urban and nonurban areas and on the detection of land use changes at the urban fringe (e.g., Friedman, 1980; Friedman and Angelici, 1979; Christenson and Lachowski, 1977). Shepard (1964) has pointed out that change detection requires less spatial and spectral resolution of the imagery than does identification of objects. Only a few studies of this nature thus have engaged in identifying land use patterns for entire metropolitan areas (Sizer and Brown, 1973; Mausel, Todd, and Baumgardner, 1974; Bryant, 1976; Hannah, Thomas, and Esparza, 1975; Baumann, 1979).

These studies of metropolitan land use patterns mainly have used Landsat Multispectral Scanner (MSS) data and produced classes of Level I and II after Anderson's land-use/land-cover classification system (Anderson et al., 1976) (Table 1). The general-level classification results have been attributed to the low spatial resolution of MSS data. In an initial spectral analysis of Mobile, Alabama metropolitan area, however, Quattrachi (1983) has discovered the difficulty in obtaining a detailed land-use/land-cover classification with Landsat-4 Thematic Mapper (TM) data of significantly improved spatial resolution using the similar methods being applied to MSS data. This finding has indicated that the procedures used in digital analysis might have affected the inability of deriving an adequate map of urban land use and that the validity of these techniques needs to be evaluated.

Efforts have been made to evaluate and compare the utilities of Landsat MSS and TM data and Thematic Mapper Simulator (TMS) data collected by aircraft (Toll, 1981; Haach, 1983; Rangaswamy and Lien, 1982). Attempts have also been made to enhance the data for better image characteristics and to reduce confusion in categorization (Podwysocki, Gunther, and Bloget, 1977; Dasarathy and Dasarathy, 1981; Nagao and Masuyama, 1979). Research workers have used the methods available for preprocessing the data and for information extraction, however, without critical examination of these techniques. The effects of preprocessing and of the invalid analytical tenhniques could have resulted in unsatisfactory land-use/land-cover classification even with flawless data. Due to the limited space, this paper proposes to examine some critical methodological issues encountered in information extraction from Landsat data and to provide an alternative technique to facilitate a more complete analysis of the data.

III. METHODOLOGICAL ISSUES

The paramount concern with regard to digital analysis for urban land use research is the filtering process involved in the analysis. The Landsat data received in the "P" format have been radiometrically and geometrically corrected at the NASA Goddard Space Flight Center (GSFC). The algorithm for the goemetric correction basically involves an averaging process in transforming original pixel data to fit a map grid system. The averaging process smooths out a certain amount of the uniqueness preserved in the data of each pixel, which are the average (reflectance or

Table 1. A List of Land-Use/Land-Cover Classes Generated in Six Different Studies*

Minneapolis[1]	Houston[2]	Milwaukee[3]	Los Angeles[4]	Orlando[5]	New Orleans[6]
Commercial Core Industrial Core Commercial/ Industrial Strip	Commercial/ Industrial/ Transportation	Commerce/ Industry	Commercial/ Industrial/ Institutional	Commercial Industrial/ New Construction	Commercial/ Industrial
High Density Single Family Res. Low Density Single Family Res. Mixed Single Multiple Family Res.	Residential Residential (New) Mixed Residential	Inner City Wooded Suburbs New Suburbs Other Suburbs	Med./High Density Residential Low Density Residential	Residential Wooded Residential	Residential 1 Residential 2
Urban Open Extractive			Undeveloped Urban Green Space Flood Channels & Extractive	Undeveloped	Open Urban Golf Course
	Woody Veg. Nonwoody Veg.	Trees Grassy Rural	Chapparal Grassland Agricultural	Trees Marsh	Forested Wetland High Marsh
	Water	Water	Water	Water	Lake/Canal River

[1]Source: Sizer and Brown 1973
[2]Source: Dornbach and McKain, 1973
[3]Source: Mausel, Todd, and Baumgardner, 1974
[4]Source: Bryant, 1976
[5]Source: Hannah, Thomas, and Esparza, 1975
[6]Source: Baumann, 1979

*The author has integrated the results of Baumann's (1976) own study of New Orleans into the results of other five studies compiled by Baumann (1976, p. 10).

emittance) values of various features within the pixel. Furthermore, Landsat data users often apply another filtering algorithm before classification. Using the SRCH (Search) subroutine of ELAS (Earth Resources Laboratory Applications Software) as an example, the "P" format data are averaged again over a three-pixel by three-pixel window in the process of generating homogeneous training fields before the fields are grouped to a smaller number of classes (Junkin et al., 1980).

These averaging and filtering processes reduce the spatial resolution and change the nature of the data. The reduction of spatial resolution through the filtering process can be clearly shown by using Clark's (1980) example of a four by four window averaging matrix (Figure 1). Jensen (1983,

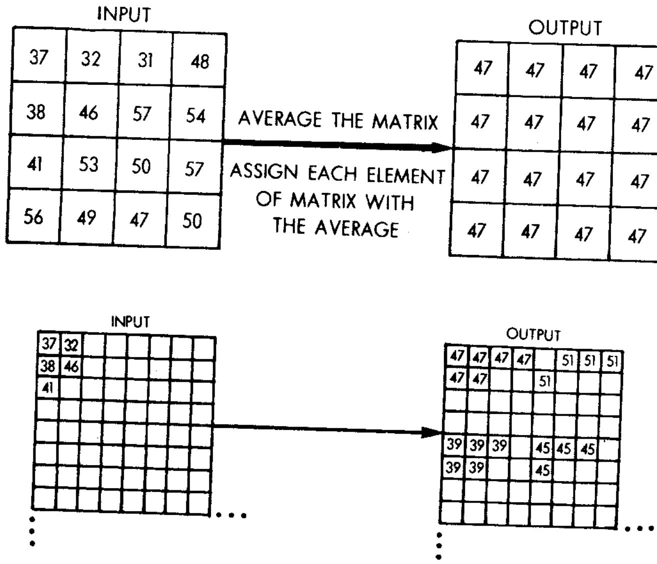

Figure 1. Reducing Spatial Resolution by Matrix Averaging (Clark, 1980, p. 48).

Figure 1. Reducing Spatial Resolution by Matrix Averaging (Clark, 1980, p. 48).

p. 1596) has indicated that "neither the MSS nor RBV Landsat-3 data are of adequate resolution for detailed studies of urban areas (IFOV's of about 79 and 40m respectively)." Both Clark (1980) and Welch (1981) have suggested that IFOV of 30m may be adequate for analysis of some urban areas in the United States. Why should the spatial resolution of either MSS or TM data be reduced through a filtering process?

The digital data from remote sensors are ordinal data with a maximum range of 256 for the 8-bit configuration and 64 for the 6-bit. The differences between data cells are relatively small compared to, for example, interval data of many other aspects, such as family income and land acreage. The data no longer differentiate one another after several times of averaging, except for those cells with extremely different spectral reflectance like water versus concrete. This is one of the reasons for the confusion between categories of agriculture and residential in land-use/land-cover classification (Smedes, Hulstrom, and Ranson, 1975; Williams and Borden, 1977).

The other methodological drawback which critically affects the results of digital analysis have resulted from the improper estimates of certain critical parameters involved in the clustering procedures. In both the supervised and unsupervised approaches of urban land use analysis, the first stage is to develop a set of keys (the mean spectral values) for various land-use/land-cover classes by channel, based on the spectral values of training sites or those of the entire study area. Each pixel in the study area is then assigned to the most similar class according to the similarity of its spectral values to the key of the class across all channels. The values of parameters in these two stages of digital analysis are often estimated on the basis of general statistics gathered from various data sets of non-urban areas and they are not suitable to urban cases. The same values are normally applied to the categories of distinct spectral characteristics. They are often either too low or too high for certain features, especially of the CBD area, to be classified (Quattrochi, 1983).

For example, both the SRCH and PTCL (Point Cluster) subroutines of ELAS discard the pixel (or subgroup) pairs when the euclidean distance of each pair multiplied by the coefficient of variation exceeds the user-specified value of the parameter, SDIS (Scaled Distance), during the clustering analysis (Junkin et al., 1980). The variation of spectral values within each urban land-use/land-cover category (within-group variation) vary widely. In other words, the average euclidean distance between pixel pairs varies from class to class, but in practice, the same SDIS value is often applied to all land-use/land cover categories with no justification to the within-group variation of each class for the discarding and clustering processes. Experiments have indicated that higher SDIS should be used for the categories with high within-group variation, such as industrial/commercial and vice versa, in order to retain the maximum number of pixels included in each training site for the development of the keys (Table 2).

The issues of filtering process and of paramater estimation involved in digital analysis have not been critical for the land use analysis of nonurban areas, because the methodology, for example, SRCH in ELAS, was originally developed for relatively homogeneous, forested and agricultural areas (Junkin, 1980). The research methods developed for forest and crop classification, however, do not readily lend themselves without modification to the analysis of extremely heterogeneous metropolitan areas.

Table 2. The Effect of SDIS Values on the Number of Pixels Retained in the Training Sites for Various Land-Use/Land-Cover Classes.

Training Sites	SDIS = 3.00	SDIS = 3.50	SDIS = 4.00	SDIS 6.00	SDIS = 7.00	SDIS = 10.00	SDIS = 15.00
CBD	1478/2617				2617/2617		
RES 1	846/894	894/894					
RES 2	435/480		480/480				
RES 3	1751/1887	1887/1887					
RES 4	713/844		844/844				
RES 5	1196/1255	1245/1255					
COM 1	298/567			567/567			
COM 2	121/259					259/259	
COM 3	1531/2407						2407/2407
IND 1	1673/2385					2385/2385	
IND 2	888/1659					1659/1659	
IND 3	490/1124					1124/1124	
IND 4	573/896					896/896	
WTR 1	2386/2386						
WTR 2	1847/1847						

RES: Residential COM: Commercial IND: Industrial WTR: Water

The numerator of each entry is the number of pixels retained after the discarding process during clustering analysis at a certain SDIS value; the denominator is the total number of pixels of each training site.

Source: Experimented and compiled by the author.

IV. ALTERNATIVE

New algorithms (abbreviated as CLUS and MDCL) have been developed at NASA/ERL, NSTL, Mississippi in response to the methodological issues discussed in Section II. CLUS is a multichannel hierarchical clustering program derived from Ward and Hook's hierarchical clustering analysis (Ward, 1963; Ward and Hook, 1963). The clustering process is based upon the similarity matrix of "D" which is the sum of the squared difference of original spectral values between each possible pair of pixels (or groups after the clustering process begins); no filtering process is involved before the grouping process. CLUS compares "NBIN" number of pixels (or groups) at one time. (NBIN, the number of bins, is the maximum number of pixels or groups allowed for processing on the computer.) CLUS treats these pixels (or groups) as separate classes and reduces one class at each clustering step by merging the pixels (or groups) with the smallest "D" value. When the pair of pixels (or groups) is merged, the mean spectral value of the pair for each channel (called the "Stat" of the group) is computed. Each merger allows room for a new pixel to be loaded onto the system and the process continues until all the pixels are merged into NBIN-1 "Stats". Those NBIN-1 "Stats" are called intermediate "Stats". The command "FP" (Final Preparation) is then used to discard the intermediate "Stats" which contain less or equal to "MAXD" number of pixels. (MAXD is the maximum to delete). NBIN and MAXD are the only two parameters specified by users; they do not directly affect the clustering analysis. The similar grouping process is applied to the remaining "Stats", reducing one "Stat" at one step, until all the "Stats" (or groups) are merged into a single class. At this stage, the program not only indicates which two "Stats" are merged and total number of classes are formed at each clustering step, but also provides a homogeneity index of the "objective function error" (OFE) for the categories formed at the step (Table 3). The "OFE" is measured as the sum of the within-group variance of all classes at each successive step of the clustering process:

$$OFE = \sum_{g=1}^{k} \frac{1}{n} \left[\sum_{c=1}^{m} \sum_{p=1}^{n} (X_{cp} - \overline{X}_{gc})^2 \right]$$

where

- c = channels (c = 1, ..., m)
- p = pixels of group g (p = 1, ..., n)
- g = groups at one step of hierarchical clustering analysis (g = 1, ..., k)
- X = spectral reflectance value of pixel p for channel c
- $\overline{X}$ = average spectral reflectance value of group g for channel c

Table 3. An Example Computer Output of CLUS

```
MERGING     19    14
CLS  25 OFE=          29960.5

MERGING     22    11
CLS  24 OFE=          30270.2

MERGING     22    16
CLS  23 OFE=          30831.3

MERGING     16    15
CLS  22 OFE=          32227.9

MERGING     22     5
CLS  21 OFE=          32831.0

MERGING     14     7
CLS  20 OFE=          34770.1

   :

MERGING      3     1
CLS   4 OFE=         107152.7

MERGING      3     2
CLS   3 OFE=         110797.9

MERGING      3     1
CLS   2 OFE=         181151.1

MERGING      2     1
CLS   1 OFE=         340923.0
```

Source: Compile by the author.

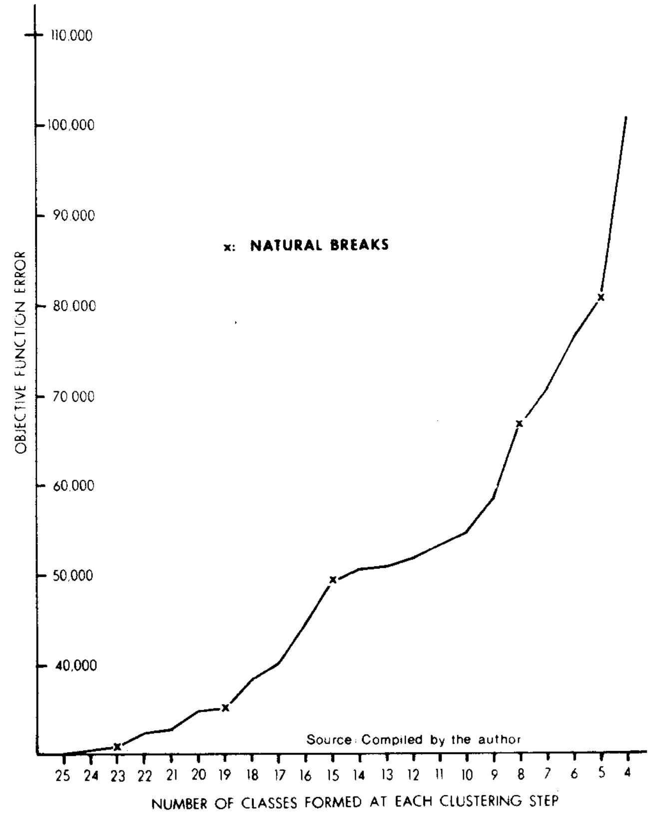

Figure 2. An Example "OFE" Profile and Natural Breaks

Each step of the clustering process implies a level of generalization. The profile of "OFES" across the steps of the clustering process brings out the "natural breaks," at which points the clustering analysis theoretically gives the most suitable classification for the levels of generalization (Figure 2). CLUS has to be used in conjunction with MDCL (Minimum Distance Classifier) which assigns (or classifies) each pixel, based on a minimum distance criterion, to one of the classes generated at a certain generalization level chosen by the user.

V. PRELIMINARY TESTS

A series of preliminary tests of CLUS/MDCL with TM data acquired over Mobile, Alabama have been performed at NASA/ERL,NSTL, Mississippi. The data (scene ID #4010315533) coincided with path 21 and row 39 of the Landsat Worldwide Reference System were collected on 27 October 1982. A data set of 512 lines by 512 elements for six channels (1, 2, 3, 4, 5, and 6) was used for the tests; channel 7 of thermal data was excluded because of the different spatial resolution of the data (Figure 3). The means, standard deviations, coefficients of variation (COV), and correlation matrix of the six-channel data are listed in the following for reference (Table 4).

Due to the massive number of pixels involved in the digital analysis of Landsat data, CLUS has to set a limit on the maximum number of classes (NBIN) to be stored in the system during the clustering process. NBIN ranges from 100 to 200 depending upon the number of channels included in the analysis. The maximum NBIN number for six-channel data is 126 and 170 for four channels. The only other parameter in CLUS, MAXD, determines the number of intermediate "Stats" to be discarded during "FP" (Final Preparation) stage; ten or less is commonly used for MAXD for TM data without additional filtering process (except for those included in preprocessing).

Three tests have been conducted at a sampling rate of every fifth line and element in an unsupervised fashion for the 512 by 512 pixel data. The first test used all six channels with NBIN of 126 and MAXD of 4; the second and third tests used four channels (2, 3, 4, and 5) with NBIN of 150 and MAXD of 4 and NBIN of 170 and MAXD of 10. These three tests have indicated that the maximum number of classes allowed on the system (NBIN) prevents the detailed classification of low-response features (i.e., forests) and restricts a legitimate separation of new residential versus the old and of categories with small differences

Figure 3. An Image of the Study Area, Mobile, Alabama

Table 4. General Statistics of TM Data, Mobile, Alabama

Channel	1	2	3	4	5	6
Mean	72.85	30.66	30.92	48.45	57.41	26.98
Std. Dev.	12.47	7.85	11.87	17.22	28.41	16.59
COV	0.17	0.26	0.38	0.36	0.49	0.62
Correlation	1.00					
	0.96	1.00				
	0.95	0.97	1.00			
	0.39	0.45	0.46	1.00		
	0.62	0.69	0.73	0.81	1.00	
	0.73	0.81	0.85	0.63	0.93	1.00

Source: Compiled by the author

in spectral respones (e.g., residence/grass versus grass/sand). The reduction of channels from six to four increases the maximum value of NBIN from 126 to 170; the increase of NBIN has resulted in a noticeable improvement in the classification with regard to the problems related to low-response features, residential conditions, and features with small differences in spectral response.

Ward and Hook's hierarchical clustering analysis compares all observations at once. It begins with each observation as a group and reduces the number of groups down to one single class. In other words, the maximum value of NBIN in CLUS should ideally be the total number of pixels included in each analysis. Most computer systems at present, however, are unable to enlarge the size of NBIN beyond 500 for multichannel data under reasonable costs. Instead of increasing NBIN, the fourth test applies CLUS to smaller areas. The study area (512 lines x 512 elements) was arbitrarily divided into three sections (219 x 512, 206 x 512, and 87 x 512). CLUS was applied to each section for four channels (2, 3, 4, and 5) at a sampling rate of every fifth line and element with NBIN of 170 and MAXD of 10. The "Stats" generated in each section of the study area were combined into 113 "Stats." These 113 "Stats" were generalized by reducing one "Stat" at each clustering step until 113 "Stats" were merged into one single class. Based upon the "natural breaks" on the profile of "OFE" values across the steps, the step with 49 "Stats" was considered the most reasonable level of generalization of land-use/land-cover classification for our purposes. The 49 "Stats" were used as the keys of land-use /land-cover categories for the entire study area. MDCL was then employed to assign each pixel of the study area to one of the 49 classes, using a minimum distance criterion.

The results of these preliminary tests are encouraging. The fourth test analyzing the study area by three sections with NBIN of 170 for each section result in the most detailed, reasonable classification among the four tests. The CLUS/MDCL algorithms in the fourth test delineated forested land covers in various types, both old and new residential areas of single-family dwellings in various densities, apartment complexes, commercial and industrial areas, golf courses, transportation networks paved with asphalt and concrete, grass and water in various conditions, bare ground, and special features such as a coal pile located at a port facility along Mobile Bay. The general pattern of clusters of the 49 categories is shown on a scatter diagram of channel-2 means plotted against channel-5 means for those classes (Figure 4).

VI. PROBLEMS AND PROSPECT

Preliminary tests have shown that NBIN values indirectly influence the results of CLUS clustering analysis. The maximum value of NBIN

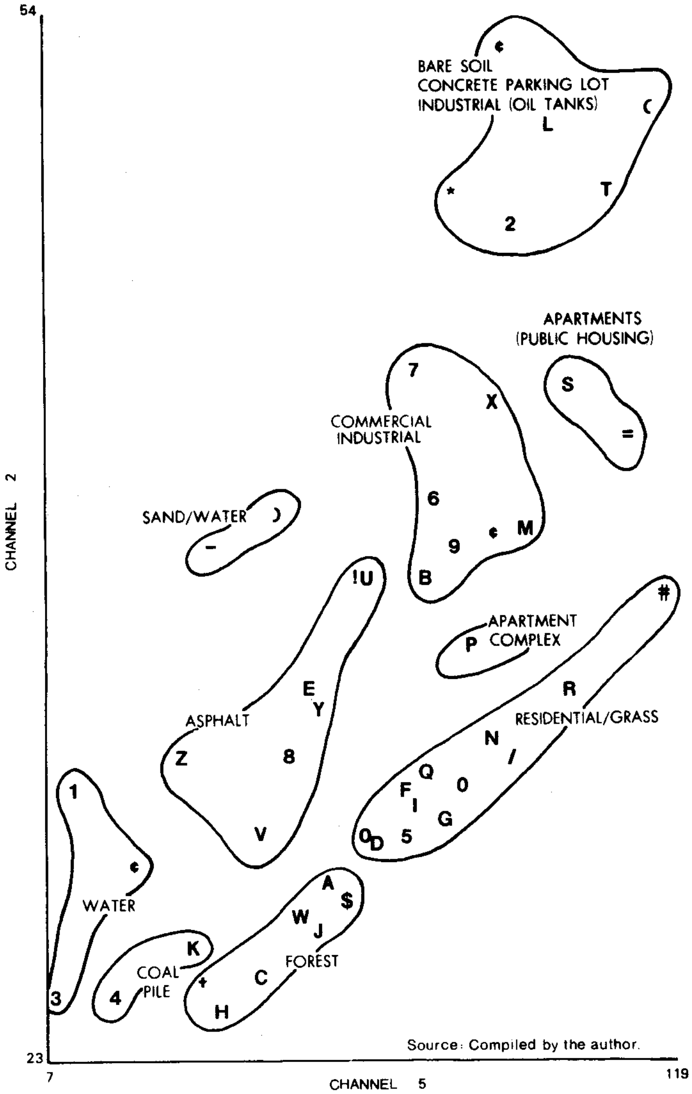

Figure 4. A Scatter Diagram of Forty-Nine Land-Use/Land-Cover Categories, Mobile, Alabama

is determined by the memory size of the computer system, which is unlikely to be easily expanded. More experiments are being carried out in applying CLUS/MDCL to finer sections of the study area with maximum NBIN of 170 for each section for four channels. The reduction of section size (or the increase of the number of sections) will enhance the chance for a greater number (or variety) of land-use/land-cover categories to be generated, when the keys ("Stats") are combined for all sections. The classification thus will contain more detailed information. These keys (or "Stats") however, stored by ELAS in "STF" file which has to be expanded in order to cope with the increasing size of the "Stats" (Junkin et al., 1980). Fortunately, the expansion of "STF" file is much more feasible and effective for better classification than that of NBIN.

The nominal radiometric correction "will not fully compensate for an improperly functioning detector" (Lillesand and Kiefer, 1979, p. 558). A noticeable band appears in the TM data image of Mobile, Alabama at a sixteen-line interval for each channel. Investigations at NASA/NSTL/ERL has found that this sixteen-line striping anomaly greatly impairs effective digital analysis of TM data. Future experiments of CLUS/MDCL should give serious consideration to the striping phenomenon and other preprocessing effects caused, for example, by geometric correction of the original data.

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